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TeRMEd: A framework for educators to aid in the design and evaluation of technology-enhanced resources in mathematics

SHORT TITLE: TeRMEd EVALUATION FRAMEWORK

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CONFLICT OF INTEREST No author associated with this paper has any potential or pertinent conflicts which may be perceived to have an impending conflict with this work.

ETHICS STATEMENT The study included the participation of students from Dublin City University, Dundalk Institute of Technology, and Maynooth University, Ireland. The students volunteered to participate and provided their consent via the institutions' ethical approval processes. The study was performed according to the ethics and research standards procedures that were in place at the time at both institutions.

DATA AVAILABILITY STATEMENT

Authors elect to not share data - Research data are not shared.

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Abstract

In this paper, we describe a classification framework which we developed and that practitioners find useful and usable in the design and evaluation of technology-enhanced resources and that incorporates factors which impact on student engagement with such resources. The classifications in the TeRMEd framework were derived from an evaluation of technology-enhanced resources, trialled within non-specialist first-year undergraduate mathematics modules. The theoretical foundation included a literature review, detailed analysis of resource trials and outcomes of the resource evaluations. Subsequently, the TeRMEd framework was evaluated by lecturers involved in the resource trials. Using the TeRMEd framework for technology integration was shown to be beneficial in terms of both design and evaluation. By carefully considering the classifications, practitioners can also encourage student engagement with resources.

KEYWORDS

Technology-enhanced resources, mathematics, pedagogical benefits, evaluation, framework, affordances

Introduction

Technology-enhanced resources have been used in undergraduate mathematics to support and enhance students' learning. They are seen as a solution to some of the problems associated with students' levels of mathematical understanding (Bray & Tangney, 2017; Howard et al., 2018; Loch et al., 2014). However, many question whether the affordances, or context-based pedagogical benefits of the technology have been fully exploited to date (Bayne, 2014; Dimitriadis & Goodyear, 2013; Kirkwood & Price, 2014). Researchers within the field of mathematics education consider the affordances of technology as being either pragmatic (where efficiencies are achieved through increasing the speed and accuracy of computations) or epistemic (where technology helps advance students' understanding of mathematical concepts) (Artigue, 2002, Drijvers et al., 2016; Monaghan et al., 2016). Other benefits of integrating technology include encouraging student engagement, motivation, satisfaction, and self-regulated learning (Galligan et al., 2015; King & Robinson, 2009; Trenholm et al., 2012). Nevertheless, it is not always clear how best to implement technology-enhanced resources to achieve these benefits (Drijvers, 2015; Conole & Alevizou, 2010; Henderson et al., 2015). This is, in part, due to the need for frameworks of evaluation that can be used to consistently and comparatively examine how technologies have been successfully integrated into education and thus use them at scale (Drijvers, 2015; King et al., 2014). Additionally, there is a call for effective instructional design processes to be used to design technology integrations that exploit the pedagogical benefits of the technologies (Allen & Sites, 2012; Branch & Kopcha, 2014; Conole, 2013; Dousay, 2017; Goodyear, 2015).

In order to address these issues, we developed the Technology-enhanced Resources for Mathematics Education (TeRMEd) framework. It acts both as a guide for lecturers in the design and integration of technology-enhanced resources, and as a tool that facilitates the gathering of evidence with respect to the success of the technology integration. To develop the framework, we first identified the factors that impact on students' successful engagement with technology-enhanced resources by trialling the use of a variety of such resources in first-year undergraduate non-specialist mathematics modules. The evaluations of these technology integrations led to the identification of 12 factors and have been reported upon in a companion paper (Ní Shé, Mac an Bhaird, et al., 2023). Once these had been identified, we were in a position to use these factors to develop the TeRMEd framework. In this paper, we address the following questions with regard to the framework:

1. How can a classification framework be developed from factors identified as impacting on student engagement with technology – a framework that aims to support practitioners in the design and evaluation of technology-enhanced resources?
2. In what ways, if any, do practitioners find the resultant framework, the TeRMEd framework, useful and usable?

Background Literature

To ensure that an effective intervention can be scaled, it is crucial to establish the indicators of a successful intervention, and how they were measured (McKnight et al., 2000). A review of literature revealed that there was little consistency in the design of research studies on the use of technology in undergraduate mathematics, and for many studies it was not clear what indicators were used to measure success. While studies predominantly used student and/or lecturer views of resources through surveys, scales or questionnaires, some used recorded usage, tests or quizzes to gauge improved student understanding (King & Robinson, 2009; Loch et al., 2012; Howard et al., 2018; Jaworski & Mathews, 2011). Other measures included class observations, task analysis, and teacher interviews and reflections (Jaworski & Mathews, 2011; Thomas et al., 2017). Few studies referenced a measure for usability, even though it has long been recognised that the usability of educational software needs to be investigated in the context of its use, as opposed to the software as a standalone product (Reeves et al., 2002; Squires & Preece, 1999). We also found a lack of explicitly-situated theoretical frameworks of evaluation within this research, which would support the evaluation and scaling of technology interventions (Drijvers, 2015; King et al., 2014).

When we searched for the integration of technology in education, we found a large number of categorisations, frameworks, models and typologies in the literature. For simplicity, we refer to these as “frameworks” within this paper. A review of these frameworks was undertaken to determine their overall scope and the features of technology integrations described and classified therein. Here, we present the frameworks that proved most relevant to our research and were used in the development of the TeRMEd framework; a full account of our larger review can be found in Ní Shé, Ní Fhloinn, et al. (2023).

There are several widely-reported frameworks for technology integration in the general literature, most notably the Substitution Augmentation Modification & Redefinition (SAMR), Technological Pedagogical Content Knowledge (TPACK) and Technology Acceptance Model (TAM) (Buchanan et al., 2013; Mishra & Koehler, 2006; Peuntedura, 2006). Within mathematics education, Bray and Tangney’s (2017) system of classification and the Formative assessment in Science and Mathematics Education (FaSMEd) (2022) framework incorporate several facets of technology use, including the type of technology, the learning theory used and the level of technology integration. FaSMEd describes how the classroom use of formative assessment technology tools has been integrated into post-primary education (FaSMEd, 2022). The framework has three interrelated dimensions: (1) agents (student, peers, teacher) who participate in formative assessment practices; (2) strategies for formative assessment; and (3) the functionalities of the technology.

A focus on “mathematical understanding” in the literature on educational technology in mathematics education is reflected in the number of frameworks that describe how mathematical learning is achieved using technology as a tool (Artigue, 2002; Kieran & Drijvers, 2016; Trgalóva et al., 2018) and how the pedagogical affordances of technology can be leveraged (Attard & Holmes, 2020; Handal et al., 2011; Hoyles & Noss, 2009; Pierce & Stacey, 2010). For example, Drijvers (2015) explored how mathematics students use technology to learn and how the teacher should exploit the pedagogical benefits of the technology. He defined the following Didactical Functions: (1) Do: the functionality related to doing mathematics, where work that could be done by hand is completed by the technology; (2) Learn – practice skills: the functionality provided to practice skills; and (3) Learn – concepts: the functionality that supports the development of conceptual understanding (Drijvers, 2015, p. 136). Handal et al. (2011) examined over a hundred mathematics educational apps and categorised them into three broad classifications: explorative, productive and instructive, with varying levels of what they called *media richness* (Handal et al., 2011). Explorative apps facilitate guided discovery and simulations; instructive apps typically focus on drill and practice; and productive apps allow students to create content such as graphs. Media richness describes the level of control the student has over the task in hand and the required cognitive load.

Finally, there are frameworks that refer to how technology is examined from the user (or student in this case) perspective. Examples of these include UDL (CAST, 2018) and the Framework for Engagement in Mathematics (FEM) (Attard and Holmes, 2020).

One aspect lacking in these frameworks is user experience evaluation, increasingly recognised as a factor in student engagement (Hong-Meng Tai et al., 2019; O’Flaherty & Phillips, 2015), and identified as a factor in the success of technology integration in mathematics education (Fabian et al., 2018; Galligan et al., 2015; Lavicza, 2010; Lee, 2014; Oates, 2010). Within the software industry, usability is often evaluated using a set of heuristics, or usability guidelines (Molich & Nielsen, 1990). Within the last decade the UK digital education organisation JISC mapped out the features of educational technology that influence a positive user experience by joining the notions of usability and user experience (JISC, 2015). This framework is based on Morville's honeycomb, which considers aspects such as how useful, usable and accessible the technology is (Morville, 2016).

Method used to develop the TeRMEd Framework

The development of the TeRMEd classification framework resulted from the outcomes of a project funded by the National Forum for the Enhancement of Teaching and Learning in Higher Education (NF) 'Assessment for Learning Resources for First-Year Undergraduate Mathematics Modules' (NF, n.d.-a). For the overall NF project, a set of resources was developed, trialled and evaluated in a number of higher education institutions in Ireland. These resources (referred to as the "NF-resources") used technology-enhanced formative assessment techniques to enable assessment for learning in mathematics (Ní Shé, Mac an Bhaird, et al., 2023). After the project was completed, based on the needs we had observed during the project, the three authors of this paper worked on developing the TeRMEd framework.

The theoretical foundation for the development of the TeRMEd framework was a literature review, detailed descriptions of the NF-resource trials and the outcomes of the student evaluations of the NF-resources (Ní Shé, Mac an Bhaird, et al., 2023). The methodology is shown in the flowchart in Figure 1.

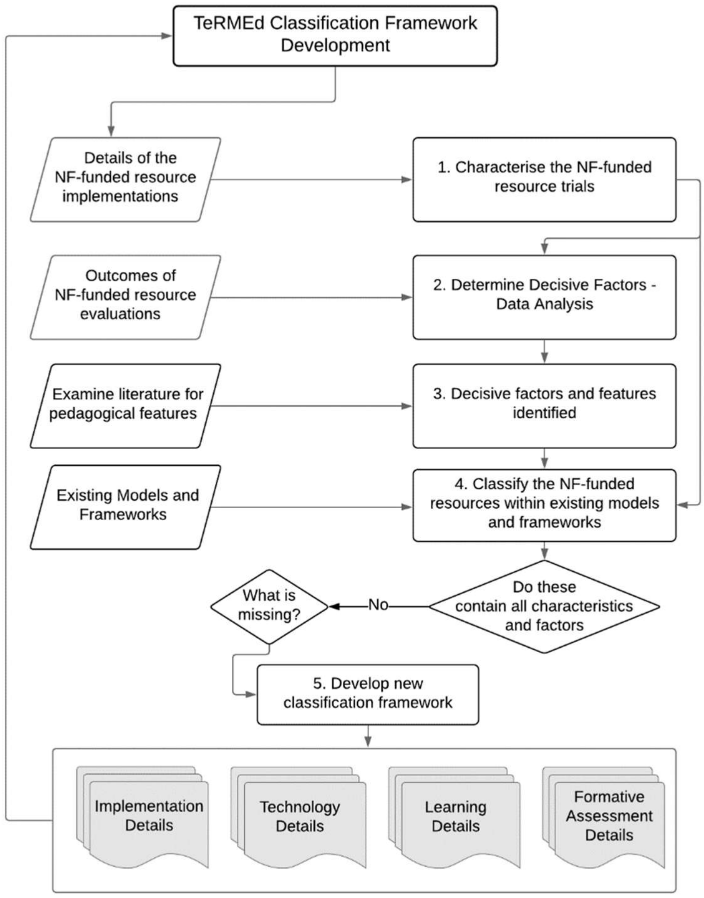

Figure 1: Flowchart of the process involved in the development of the TeRMEd framework.

Steps 1 to 3 in Figure 1 identified the following 12 factors of technology integration that impact on student engagement with the technology (Ní Shé, Mac an Bhaird, et al., 2023):

1. use in class
2. grade associated with its use
3. class size
4. student cohort
5. task design
6. purpose
7. instructions on use
8. user experience

9. affordances
10. formative assessment
11. technology type
12. collaboration with peers

In step 4 of the flowchart, existing evaluation frameworks were investigated to determine how technology integration is currently classified, and whether all 12 factors identified were contained within these frameworks. As they were not, a new classification system was developed, the TeRMEd classification framework, which was the fifth step in the process illustrated in Figure 1. This was an iterative process, whereby all three authors regularly met to review and discuss the development of the TeRMEd framework. The outcomes of the four stages of the development of the model were repeatedly reviewed, to ensure nothing had been overlooked. This aligns with the processes required for validity in such studies (Thomas, 2006; Worren et al., 2002).

Once the TeRMEd framework was developed, five of the lecturers involved in the original NF-project (which first highlighted the need for this framework) were asked for their opinions of the framework and its potential value within their own practice. They had no involvement in or knowledge of the development of the framework, and as such were able to respond as independent practitioners. They were chosen for this pilot as we knew they had recent experience of implementing formative assessment using technology in their mathematics classroom. A detailed questionnaire was sent to these lecturers (see Appendix A), and the analysis of their responses was used to confirm the framework as an instrument for practitioners in the field. This evaluation process provides validity in terms of a pragmatic study as suggested by Worren et al. (2002). The questionnaire was carefully designed to elicit responses about all aspects of the framework and structured to ensure face and content validity through examination of the literature in this area and consultation with expert practitioners (MacGeorge et al., 2008; Pierce et al., 2007). In order to facilitate the lecturers in engaging with the TeRMEd framework, they were given an 11 page document, available in the doctoral thesis (Ní Shé, 2021), describing the key features of the framework, and how the NF-resource they used in the overall project would subsequently be classified. This narrative and visual representation of the TeRMEd classification framework provided an extra level of validity to the study, which Worren et al., (2002) noted as lacking in many pragmatic studies.

The quantitative aspects of the completed surveys were analysed in Microsoft Excel and the qualitative data was imported into NVivo for general inductive analysis according to the guidelines suggested by Thomas (2006). Thomas's five step approach to inductive analysis was used to derive themes through iterative interpretations of the raw data, a process that is readily supported by NVivo where raw data is coded into nodes that are then linked to themes and sub themes.

The TeRMEd Framework Development

Although no single existing framework encompassed all 12 factors identified above, some of their classifications could be used to capture one or more factors, and so existing frameworks were reviewed with this in mind when developing the TeRMEd framework. Table 1 contains a list of the frameworks considered and a brief rationale behind the inclusion or exclusion of their elements within the TeRMEd framework.

Table 1: Models and Frameworks used to classify technology use

Model/Framework	Purpose	Included	Rationale to include/exclude
Instrumental Orchestration (Artigue, 2002; Kieran & Drijvers, 2016; Thomas et al., 2017; Lopes & Costa, 2019)	Converts digital tools into artefacts, connects technical skills & conceptual understanding required	No	Complex set of elements to describe how students develop mathematical understanding. Used by researchers – not a focus for practitioners.
Experimental mathematician (Borwein, 2005)	Provides a list of 8 ways experimental mathematicians use computers	No	Solely concerns specific affordances of technology.
SAMR (Puentedura, 2006)	Characterises how technology tools adopted into existing education environment	No	Focus on tasks technology supports. Technologies used by NF-resources can support more than one task, and more than one of SAMR levels.

TPACK (Mishra & Koehler, 2006)	Framework that considers intersection of teachers' knowledge on technology, pedagogy and content is key to successful technology integration	No	While this framework covers the teacher knowledge requirements for technology integration, it does not incorporate their design and evaluation.
Categories of digital tools. (Hoyles & Noss, 2009)	Four categories of tools: (1) dynamic & graphical (2) tools that outsource processing power (3) new representational infrastructures (4) connectivity that supports mathematics activity	No	Categorisations useful in consideration of technology section but did not encompass all inherent and pedagogical affordances of technologies used in NF-funded project trials.
Pedagogical opportunities (Pierce & Stacey, 2010)	Map of 10 pedagogical opportunities, grouped into 3 levels: (1) Task set (2) Classroom interaction (3) Mathematical topic	No	Concepts fruitful in developing educational context (classroom & didactics); map focusses on MAS technology. NF-trials implemented other technology types in addition to MAS.
Mobile App categorisation (Handal et al., 2011)	Categorises use of mobile apps for schools based on instructional roles & media richness as: productive, explorative, & instructive	Yes	Allows categorisation of pedagogical affordances that different technology types can support.
TAM (Buchanan et al., 2013; Nikou & Economides, 2017; Zogheib et al., 2015)	Theorises usage behaviour of technology - Perceived usefulness & Perceived ease-of-use	Partially	Concept of 2 scales - considered and reflected in user experience section of TeRMEd framework.

Didactic Functionalities (Drijvers, 2015)	3 didactical functions supported by technology: (1) Do (2) Learn – Practice Skills (3) Learn-concepts	Yes	Suitable as classification of different task types used in NF-resources.
User Experience Honeycomb (Morville, 2016)	Attributes of technology deemed desirable to enhance student experience of using technology	Partially	7 attributes considered in line with questionnaire items used in NF-resources survey evaluations.
Bray and Tangney (2017)	Technology Classification System (general characteristics of technology-enhanced interventions in mathematics education)	No	Learning theory & intervention aim characterisations outside scope of TeRMEd framework. Technology classifications relevant but did not adequately describe all technology types evident in NF-funded project resources.
Didactic Tetrahedron (Trgalová et al., 2018)	Examines digital tool use as interactions between (1) tools & knowledge (2) tools, knowledge & learner (3) integration of tools in curriculum or classroom	No	Tool to understand how students interact with technology to achieve mathematical understanding. Used by researchers – not a focus for practitioners.
FEM (Attard & Holmes, 2020)	3 aspects: Pedagogical Relationships (between students and teachers), Pedagogical Repertoires (teacher day-to-day teaching practices), and Student Engagement (factors that support engagement)	No	This framework focusses on the practices of teachers and their interactions with students. It does not include how the technology is designed and evaluated.

FaSMEd (2023)	Characterises aspects of secondary-level classroom use of formative assessment technology tools	Partially	Focus on technologies used within classroom at secondary level. Insufficient categorisations to include all factors identified for NF-resources.

Having reviewed these existing frameworks, and with the aim of including all 12 factors in the TeRMEd framework, four main "sections" were defined: Implementation; Technology; Learning; and Formative Assessment (Figure 2). Each "section" has between one and three "categories". In Figure 2, rectangles represent original content; ovals represent content from existing frameworks; half/half represent content from existing frameworks modified by the authors, or some subcategories developed by the authors, and some developed by others.

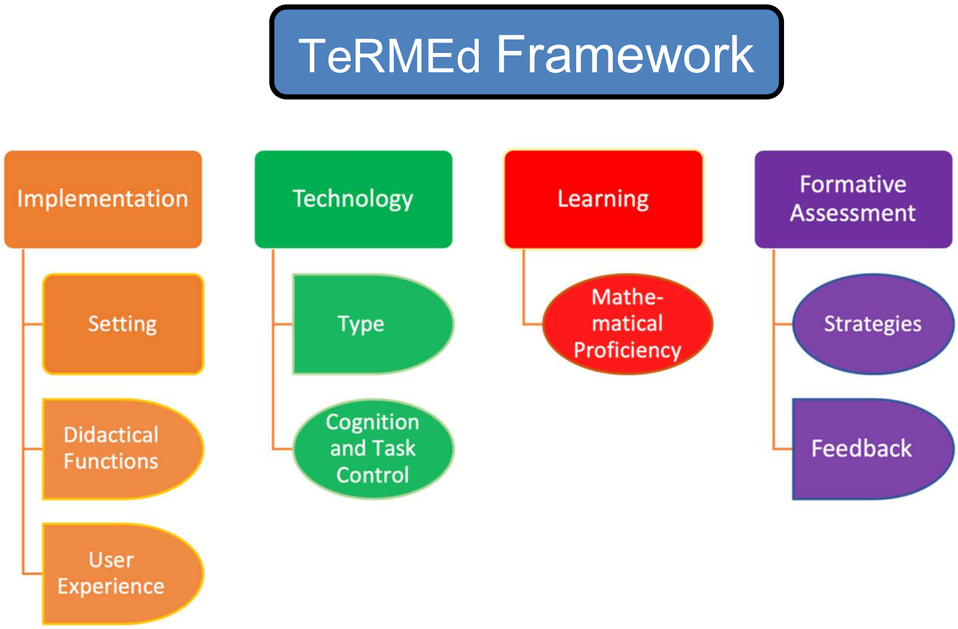

Figure 2: Contribution to knowledge made by the TeRMEd framework

The Implementation section characterises the educational setting, the didactical functions of the technology (Drijvers, 2015) and the user experience (Buchanan et al., 2013; Molich & Nielsen, 1990; Morville, 2016; Zaharias & Poylymenakou, 2009). The technology type

(FaSMEd, 2022), and the level of cognition and user task control (Handel et al., 2011) afforded by the technology are defined in the Technology section. The characteristics of the types of expected mathematical proficiency (National Research Council, 2001, pp. 115 - 145) are covered in the section on Learning. Finally, the strategies (FaSMEd, 2022) and feedback (Hattie and Timperley, 2007) supported by the resource are characterised in the Formative Assessment section.

Figure 3 illustrates how the 12 factors are encompassed in the design of the TeRMEd framework. At least one of the factors contributed to the development of each category within the framework, and in some cases a factor contributed to more than one section.

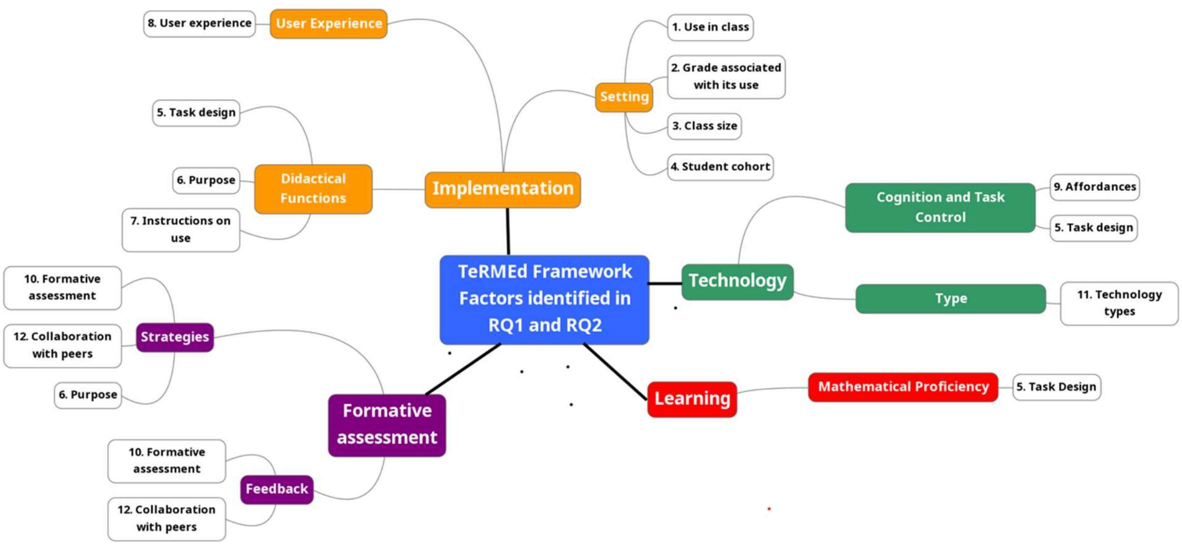

Figure 3: Encompassing the 12 factors within the TeRMEd framework

The Implementation section is the most complex of the four and contains the only entirely original category ("Setting"), so details of how this was developed are given below as an example of the approach taken throughout the framework development, which is given in full in Ní Shé (2021). The full framework (including all categories and subcategories) can be found in Appendix B.

Implementation Section of the TeRMEd framework

The Implementation section has three categories: Setting; Didactical Functions; and User Experience, each with the subcategories shown in Table 2.

Table 2: The TeRMEd framework: Implementation Section.

<table>
<tr><th>Section</th><th>Category</th><th>Subcategory</th><th>Options</th></tr>
<tr><td rowspan="22">Implementation</td><td rowspan="10">Setting</td><td rowspan="3">Student Numbers</td><td>Small < 30</td></tr>
<tr><td>30 ≤ Medium < 100</td></tr>
<tr><td>Large ≥ 100</td></tr>
<tr><td rowspan="3">Situation</td><td>Lecture only</td></tr>
<tr><td>Study time only</td></tr>
<tr><td>Both lecture & study time</td></tr>
<tr><td rowspan="2">Summative Assessment</td><td>Yes</td></tr>
<tr><td>No</td></tr>
<tr><td rowspan="2">Student Cohort</td><td>Non-specialist</td></tr>
<tr><td>Specialist</td></tr>
<tr><td rowspan="7">Didactical Functions</td><td>Do</td><td rowspan="3"></td></tr>
<tr><td>Learn - practise skills</td></tr>
<tr><td>Learn – concepts</td></tr>
<tr><td rowspan="4">Lecturer Instructions</td><td>Instructions</td></tr>
<tr><td>Purpose</td></tr>
<tr><td>Instructions & Purpose</td></tr>
<tr><td>None</td></tr>
<tr><td rowspan="3">User Experience</td><td>Navigation</td><td>Likert scale (Student Survey)</td></tr>
<tr><td>Usable</td><td>Likert Scale (Student Survey)</td></tr>
<tr><td>Learnability</td><td>Likert Scale (Student Survey)</td></tr>
</table>

		Accessibility	Dynamic or Static
		Consistency	Dynamic or Static
		Visual Design	Dynamic or Static
		Technologically ready	Dynamic or Static
		Useful	Likert Scale (Student Survey)
		Usage	Recorded by technology/ lecturer

Note the numbering scheme used for the factors in the methodology section is continued here for clarity.

Implementation - Setting

As mentioned above, the category "Setting" was the only fully original one in the framework. The sub-categories and options that stem from Setting were determined, in consultation with the literature, as a result of the following four factors:

1. use in class
2. grade associated with its use
3. class size
4. student cohort

The factor 'class size' determined the first subcategory, Student Numbers. In the literature on the impact of class size on student learning in higher education, there is little consensus as to the number of students that constitute a 'large class' (Dean & Wright, 2017). Fischer and Grant (1983, as cited in Cuseo, 2007, p. 7) defined small classes as 15 or fewer, medium as 16 – 45 and large classes as 46 or more. Alternatively, large classes were defined as ones where student learning is negatively affected (Hornsby & Osman, 2014) or where interactions with and by students is constrained (Dean & Wright, 2017). Based on observations during the larger NF project on how technologies impacted within different class sizes, the Student Numbers sub-categories were set to Small < 30, 30 ≤ Medium < 100, and Large ≥ 100.

The Situation subcategory stemmed from the 'use in class' factor: the effect on student engagement of using the NF-resources in prescribed class time (as demonstrated and stipulated by the lecturer) versus in students' own time. This subcategory aligns with the theoretical underpinnings of instrumental orchestration, where use of the technology by students in class with lecturers/teachers is encouraged to ensure instrumental genesis, i.e. to enable students to be able to use educational technology effectively (Thomas et al., 2017).

The Summative Assessment subcategory was created as a result of the 'grade associated with its use' factor, and evidence that suggests that students are more likely to engage in learning assessments that contribute towards their grade (Gibbs, 2010).

The final Setting subcategory, Student Cohort, takes into account the ability and attitude of the particular student group, and their assessment of their own need for technology-enhanced resources. It has been shown that students taking non-specialist mathematics modules often do not have the required mathematics level (Faulkner et al., 2010; Gill & O'Donoghue, 2007), and the analysis of the NF-resources revealed that these students are more invested in achieving the required grade than developing mathematical understanding.

Implementation - Didactical Functions

The Didactical Functions category encompasses the following three factors:

5. task design
6. purpose
7. instructions on use

It captures the need to take into account how the teacher puts the digital tool into effect. This has been identified as important for effective technology implementations in the classroom (Drijvers, 2015). Therefore, it is necessary to characterise the pedagogical functionality that is enabled by teachers' implementation of the technology. The Drijvers' (2015) model of Didactical Functionality (Do, Learn – Practice Skills, Learn – Concepts) is used to describe how the pedagogical functions of the resources can be exploited by the lecturers. The inclusion of didactical functionality takes into account the need for the 'task design' factor. In addition, two factors that encompass didactical practices are the need for clarity of 'purpose' and 'instructions on use' of the resource. Therefore, an additional didactical function, Lecturer Instructions, was developed for this category. This refers to the didactical practices of the lecturer - specifically, provision of purpose and instructions - when implementing the technology. The need to consider these didactical practices has also been discussed within the instrumental orchestration theoretical framework (Jupri et al., 2016; Kieran & Drijvers, 2016; Thomas et al., 2017) and the didactical tetrahedron (Trgalová et al., 2018). The options for this sub-category are: Instructions, Purpose, Instructions & Purpose, None.

Implementation – User Experience

The third category in the Implementation section is the User Experience. This category stems from the 'user experience' factor (factor 8) and refers solely to the experience of the students in this context, and not that of the lecturer. User experience has long been a concern of the education community with respect to the selection of educational software for use by teachers (JISC, 2015; Squires & Preece, 1999). The addition of this category supports the belief that the user interface impacts on student engagement, and hence learning from using the resource (Bond & Bedenlier, 2019). There are many different usability and user experience factors that have been investigated in the development and use of technology in education (Buchanan et al., 2013; Molich & Nielsen, 1990; Morville, 2016; Zaharias & Poylymenakou, 2009), all of which were consulted when developing the subcategories of the User Experience of the TeRMEd classification framework. These were used in the development of the nine User Experience subcategories, which are described below:

- Navigation: Learners can navigate their way around resource without seeking help
- Usable: Learner's perception of how easy-to-use they find resource
- Learnability: Learner's perception of how their learning has been enhanced using resource
- Accessibility: Resource is accessible and follows UDL principles
- Consistency: Consistency of terminology, design and functionality within resource
- Visual Design: Screen is easy to read, and information is placed in optimal places to attract learners' attention
- Technologically ready: Resource is free from technical problems
- Useful: Learners' perception of how useful they find resource within the context
- Usage: Percentage of learners who used resource

Practitioners can use the TeRMEd framework to both plan and evaluate technology-enhanced resources that they intend using in the support of students' learning. In the planning stage, when a practitioner is considering how to integrate a resource, they can use the TeRMEd framework to design the features of technology that best support their learners' needs. However, the User Experience category cannot be fully completed until after the resource has been implemented, in the evaluation stage. This is because four of the subcategories stem directly from four items that are to be asked of students (in anonymous surveys) after they have utilised the technology integration. These four items are: Navigation; Usable; Learnability and Useful. For example, the percentage of students who were positive about how easy to use they found a resource will be the value for the Usable subcategory. The Usage subcategory is the percentage of students who used the technology as recorded either electronically or by the lecturer themselves. This data will be entered into the framework to facilitate the practitioner in their consideration of how effective the technology integration has been, and what changes might be required for future integrations.

The remaining options for the User Experience subcategories are set by a static/dynamic value, which indicates whether the feature is controlled by the product designer (static) or the lecturer (dynamic). For example, the Accessibility subcategory will be static when the technology used cannot be modified by the lecturer and dynamic if it can be.

TeRMEd Framework Validation

Having developed the TeRMEd framework, we then conducted a pilot validation process, involving five of the members of the original NF-project, all of whom had recently implemented technology-enhanced resources in their teaching. There were three different resources trialled within the NF-project: UniDoodle – an audience response system with free-form input for use in mathematics lectures; Khan Academy (KA) playlists and mastery challenges implemented via Moodle; and a suite of interactive tasks using GeoGebra and Numbas. Two of the lecturers had run separate UniDoodle trials, referred to as UD1 and UD2; two were involved in three different Khan Academy trials, of which one managed KA1 and KA2, and the other managed KA3; and one who was involved in two GeoGebra trials. Students' usage of the resources had been recorded and their opinions of the resources were sourced from student surveys, so these were used to fulfil the User Experience aspect of the TeRMEd framework. Each of the five lecturers were sent a completed version of the TeRMEd framework for the NF-resource they implemented, so that they could see how the various sections and categories would apply to their implementation.

The aim of the TeRMEd framework validation was to determine if the lecturers found the TeRMEd framework both useful, in terms of it being relevant to their practice, and usable, in terms of their intention to use it in future technology integrations. Note that validation here refers to the provision of a sound basis for practitioners in the design and evaluation of technology-enhanced resources.

In the first instance, lecturers were asked if they had taken each of the categories and subcategories into account prior to the development of the trial of their NF-resource, selecting Yes/No/Unsure on a range of items. The items were grouped according to the TeRMEd framework sections, and at the end of each section, they were asked to comment where relevant (Ní Shé, 2021).

Figure 4 illustrates that, while not every category was taken into account in every trial, every category had been considered by at least one lecturer.

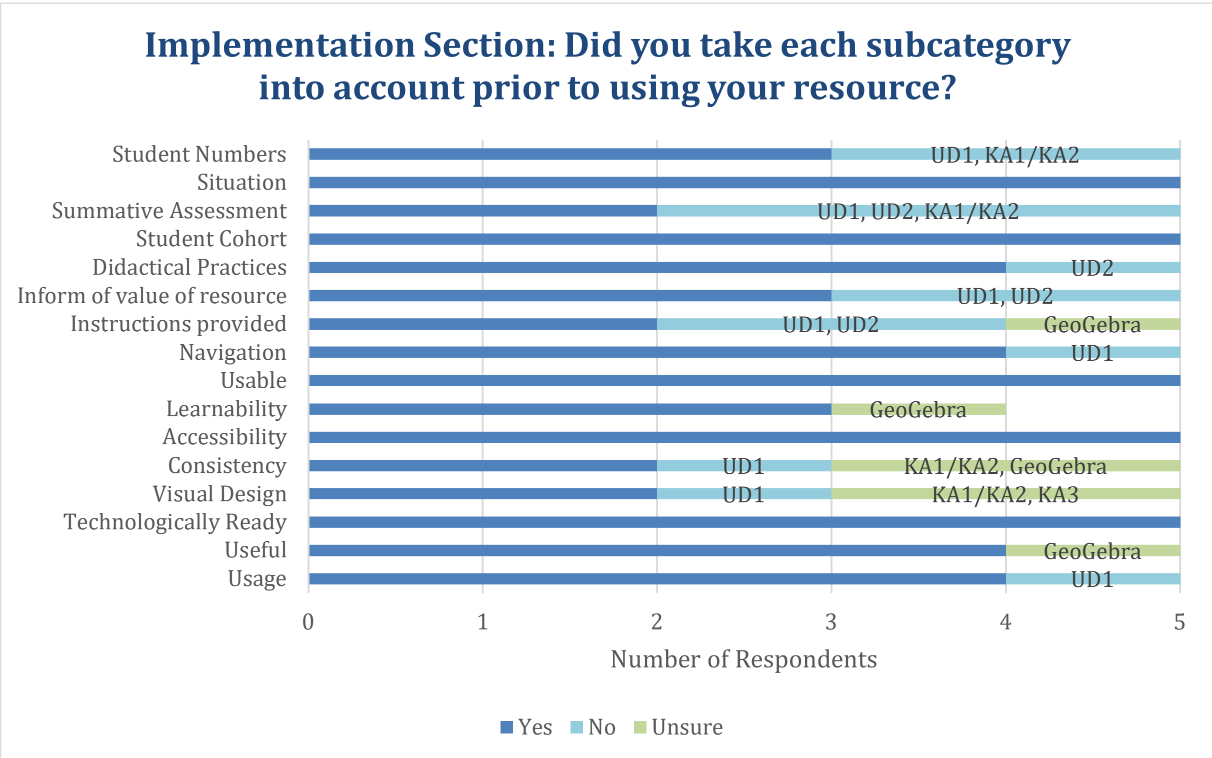

Figure 4: Practitioners' responses to the Implementation section. Note: the KA3 lecturer did not provide a response for "Learnability".

Furthermore, the relevance of categories that had not been considered prior to the integration of the resource was evident in lecturer comments. For example, the KA1 and KA2 lecturer commented that she had no control over some user experience categories, such as accessibility. This response validates the choice to provide a 'static' and 'dynamic' option within the framework. Also of note is that, while the UD2 lecturer may not have been familiar enough with the Didactical Practices to select that he had considered them, his remarks illustrated that he had, in fact, done so: '*Specifically, what concepts would benefit most from being addressed in this graphical manner, and how to best phrase questions to ensure that students would use their visual understanding of the mathematical concept*' (UD2 Lecturer).

Similar results were found for each of the Technology, Learning, and Formative Assessment sections, with at least one lecturer (and generally three or four) agreeing that they had taken each category into account in advance. The only exception to this was the "adaptive reasoning" category of the Learning section, where two lecturers said no and the others were unsure. However, comments made by the lecturers in this case showed that they had taken it into account but were unsure of the terminology.

Secondly, lecturers were asked whether they would have predicted the outcomes of the survey contained in the User Experience categories of student opinions and usage: the lecturers, with a few exceptions, agreed that they would (Figure 5).

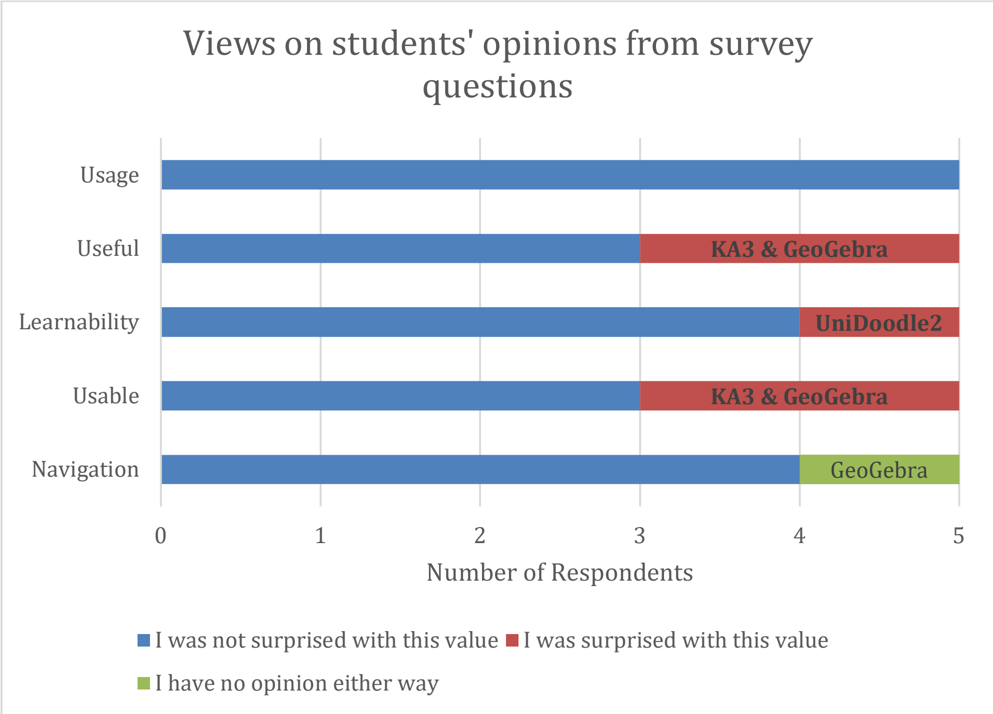

Figure 5: Lecturers' surprise or otherwise on students' opinions

Lecturers were asked to comment on any discrepancies; their remarks indicated that the data would help them reconsider how they had integrated the technology. For example, the UD2 lecturer expressed concern that many students had not rated Learnability highly (Ní Shé, 2021). He remarked that students may not have liked to be forced into engaging graphically and visually with mathematics, '*but (I) am a little surprised that more students did not see the value of it*'. Despite having given considerable time to the development of tasks, the lecturer goes on to say that '*Perhaps this is my fault for not reinforcing the concepts well enough during the exercises*'. The use of the evaluations within the TeRMEd framework has prompted this lecturer to reflect on his teaching.

Another example involved the KA3 trial. Although he considered that KA was easy to navigate, the KA3 lecturer was not surprised that students stated they found it hard to navigate, '*…While students tend to need some instruction in navigating new platforms, they seem to be able to do so when there is a strong incentive, e.g. because CA marks are at stake*' (KA3 lecturer). He went on to suggest that he may use continuous assessment (CA) in future integrations of this resource.

All the lecturers stated that the values within the User Experience classification, generated from the student survey data, would drive future technology integrations, '*In future implementations I would re-examine the classifications and consider whether anything could be done to improve on the values in some subcategories where values were low or missing*' (GeoGebra lecturer).

Thirdly, lecturers were asked whether the categories and subcategories of the TeRMEd framework had helped them identify factors that they should have taken, or would in the future take, into consideration to improve student engagement. Once again, all pointed to one or more category or subcategory. For example, the UD1 lecturer had not considered all the strands of Mathematical Proficiency and expressed his desire to consider them in the future, '*I would like to see if I can use the UniDoodle resource to capture more than just the "conceptual understanding"*'. The lecturer in GeoGebra trials said she had not considered how Feedback Direction might impact on student engagement and that '*activat(ing) students as instructional resources for each other...could propagate the learning taking place or enable peer teaching (learning)*'. Specifically, the framework had made the lecturers think about these aspects, for example '*I wasn't familiar (or hadn't really thought about) the various sub-aspects within these sections*' (UD1 lecturer).

Lastly, the lecturers' comments indicated that they found the TeRMEd framework valuable in numerous ways. Firstly, one felt that '*The framework is very comprehensive and allows one to compare various tools on many different aspects/using many different criteria*' (GeoGebra lecturer). Another liked that '*It provides a useful design tool that I would take into consideration for future use of KA or other resources*' (KA3 lecturer). The UD2 lecturer considered it useful for '*Sharing of experience between practitioners to ensure best practice*.' Finally, the UD1 lecturer stated that '… *if I have the document in front of me with the detailed breakdown of categories, it would focus my mind on a range of aspects to consider in the use of any new resource I would consider using*'.

Discussion and Conclusion

We have shown that the use of the TeRMEd framework for technology integration within undergraduate mathematics education is beneficial in terms of both design and evaluation. Practitioners expend considerable time developing such resources (Quinn et al., 2015; Trenholm et al., 2015, 2016); the TeRMEd framework can help ensure that this work is put to best effect. It enabled the lecturers to reflect on their practice and focus on the decisive factors that encourage student engagement with technology-enhanced resources. There are certain limitations with this validation of the TeRMEd framework. All five participants were based in Irish HE and each commented on a completed version of the TeRMEd framework. In practice, they themselves would complete the TeRMEd framework themselves. The following discussion should be viewed under the lens of these limitations.

The TeRMEd framework addresses issues identified in the literature; taking advantage of the pedagogical benefits of technology (Conole, 2013; Goodyear, 2015; Bond & Bedenlier, 2019); using consistent frameworks of evaluation (Drijvers, 2015, King et al., 2014) and supporting practitioners in instructional design (Conole, 2010; Goodyear, 2015). It also addresses the need to focus attention on the educational setting, the didactical practices and the design of the technology use, a need identified by Drijvers (2015). In addition, the variation in usage and student opinion of the technology in use are captured, in order to evaluate the technology integration. Practitioners can use this information to redesign future iterations of the technology integrations.

While many of the classifications of the TeRMEd framework can be completed prior to the integration of the technology within a mathematics module, a number of user experience subcategories are populated using student evaluations (Table 2). It is this unique feature of the classification framework that enables the practitioner to reflect on the success or otherwise of the technology integration from their students' point of view. When presented with the TeRMEd framework classification and user experience evaluations of the NF resources, the lecturers involved in the pilot validation voiced surprise at some of the evaluation data. As a result, they plan to make modifications to some of technology integration features contained within the TeRMEd framework classifications, specifically those that predict more successful engagement with the resources. While these recommendations with respect to technology integration have been acknowledged in the literature (Bond & Bedenlier, 2019; Drijvers, 2015; Thomas et al., 2017), practitioners may not be overtly aware of them. Indeed, the provision of the detailed feedback classification within the TeRMEd framework can help practitioners carefully design feedback interventions to ensure students' performance is enhanced rather than attenuated, as has been shown in prior studies (Hattie & Timperley, 2007; Kluger & DeNisi, 1996). Thus, including these features in a framework such as the TeRMEd framework means that practitioners will have them to hand when developing resources.

An emphasis on instructional design processes that support effective pedagogical practices is considered essential in enabling educators to leverage the affordances of technology (Conole, 2013; Goodyear, 2015; Laurillard, 2012). Indeed, it has been found that design which exploits the pedagogical affordances of technology enhances student engagement (Yang et al., 2018). By embedding pedagogical practices that are known to support student engagement with technology within the TeRMEd framework, practitioners can use the framework to support their instructional design process. All the lecturers indicated they would use the TeRMEd framework when planning future uses of technology within their teaching. Some suggested that they were unaware of certain pedagogical features, such as Didactical Functions, and the various strands of Mathematical Proficiency. The use of the TeRMEd framework has prompted them to further investigate these pedagogical practices for future technology integrations.

One of the key additions of the TeRMEd framework to the discourse on how best to integrate technologies in education is the inclusion of 'User Experience' as a category. Features such as the usability and learnability of course materials are increasingly recognised as having an impact on student engagement (Bond & Bedenlier, 2019; JISC, 2015; Squires & Preece, 1999; Zaharias & Polymenkau, 2009). There is increasing recognition that instructional design needs to take on aspects of software design, such as a focus on user experience requirements (Adnan & Ritzhaupt, 2018; Svihla, 2018). Indeed, in the recent Irish National Digital Experience (INDEx) Survey, one of the key findings was student requests for consistency and improved navigability across the institutional VLEs (NF, 2020). It is thus timely to include such features in a classification framework such as the TeRMEd framework.

Further research into its practicability as a resource to support the design and implementation of effective resources is an obvious next step. Indeed, it could prove valuable to investigate the relative benefits of using the TeRMEd framework, before or after a first implementation of a resource.

Finally, the TeRMEd classification framework that emerged from this research could be used in a wider context, not only within other higher education mathematics contexts, but in other disciplines. Many of the categories and subcategories defined within the TeRMEd framework can apply, with some minor adjustment, to any technology integrated into education.

For example, the didactical functions could be replaced by pedagogical opportunities that are pertinent to the specific discipline, such as when podcasts are used to support language learning with authentic materials (Rosell-Aguilar, 2007). The Learning section currently contains only mathematics-specific material, but could instead contain categories of the discipline-specific understanding or learning required: for example, in language learning, there may be a reference to grammatical skills, vocabulary (Alqahtani, 2015) and communicative competence (Canale, 1983). Further consultation with discipline-specific experts and research literature in those areas is required to modify the TeRMEd classification framework for such use. The modified form of the TeRMEd framework could then be used and evaluated in future technology integration projects undertaken in those disciplines.

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